Stewart & Mc Cool

Nozzle Piezometer Tests

Civil Engineering

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NOZZLE PIEZOMETER TESTS

BY

JAMES SAMUEL STEWART
CHARLES EDWARD McCOOL

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED, JUNE, 1909

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June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CHARLES EDWARD McCOOL and JAMES SAMUEL STEWART

ENTITLED NOZZLE PIEZOMETER TESTS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

F. B. Sanborn
Instructor in Charge

APPROVED: John P. Brooks

HEAD OF DEPARTMENT OF Civil Engineering

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INTRODUCTION.

The American Nozzle Piezometer, which is the piezometer used in these tests, was designed by F. B. Sanborn M. Am. Soc. C.E., and is an instrument whose purpose is to indicate the hydraulic pressure and the corresponding amount of flow at the mouth of a nozzle. At present it is on the market in two common sizes, one graduated for 1/2- and 1 inch nozzles , and the other for 2- and 4 inch nozzles, but these two will also fit on any intermediate sizes. The instrument consists of a cut-water through which pressure is transmitted to a gauge which indicates directly both the pressure, and the quantity of water that is flowing. In practice it is useful for water departments, insurance inspectors, and fire departments.

The photographs and cuts on pages 2 and 3 show the piezometer and its operation.

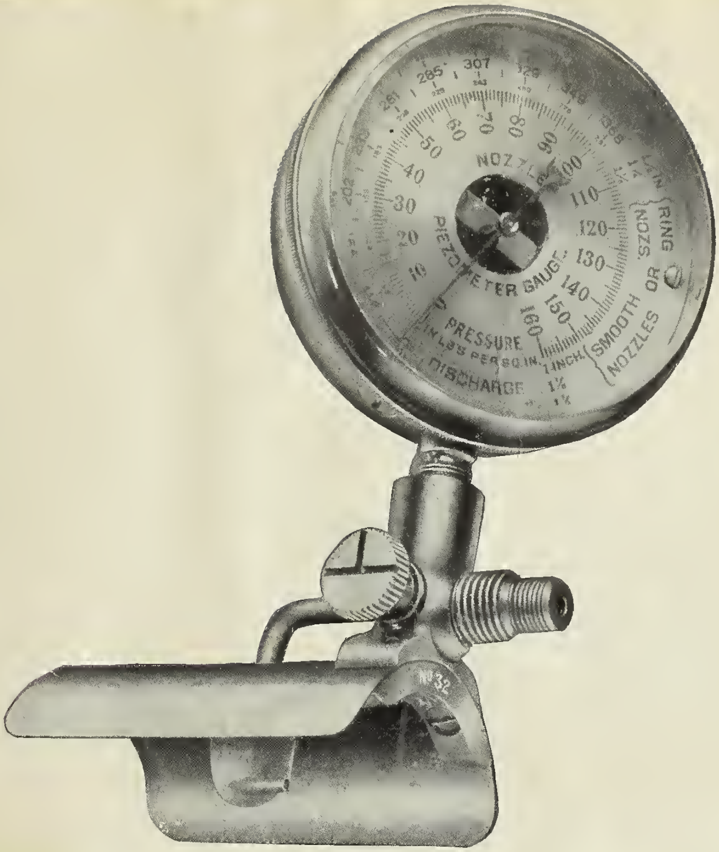
OBJECT.

The objects of these tests was to determine the accuracy of the piezometer as it would commonly be used, and to ascertain the limitations of its field of accuracy.

DESCRIPTION AND GENERAL ARRANGEMENT OF APPARATUS.

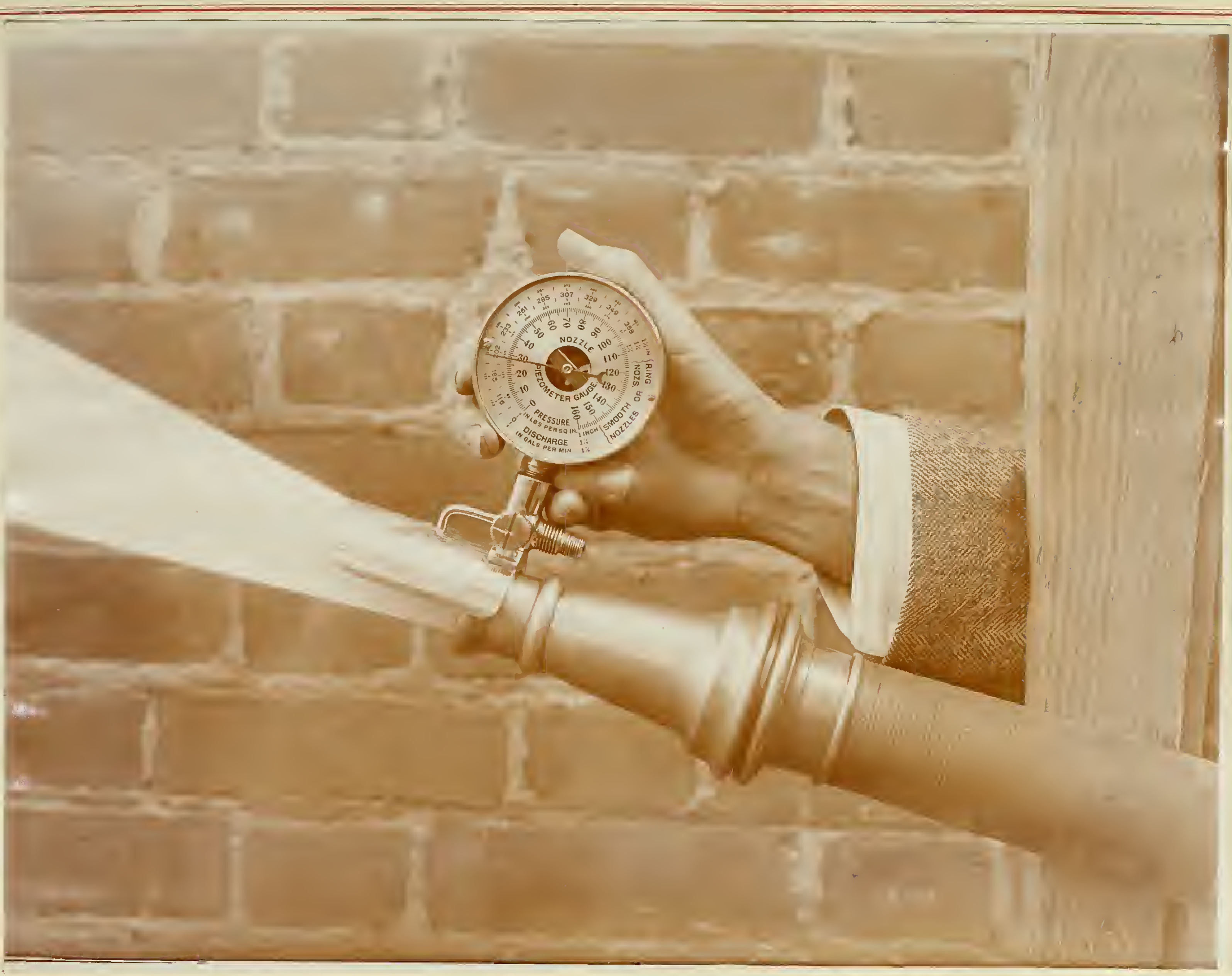
Owing to the fact that these tests were of a nature not before attempted in the University laboratory very little of the required apparatus was at hand and it was necessary to spend considerable time in the design and arrangement of new apparatus. The general arrangement of discharge pipe and nozzles was planned by us and put in place as shown in Plate I.

The set of nozzles used, with their attached piezometer

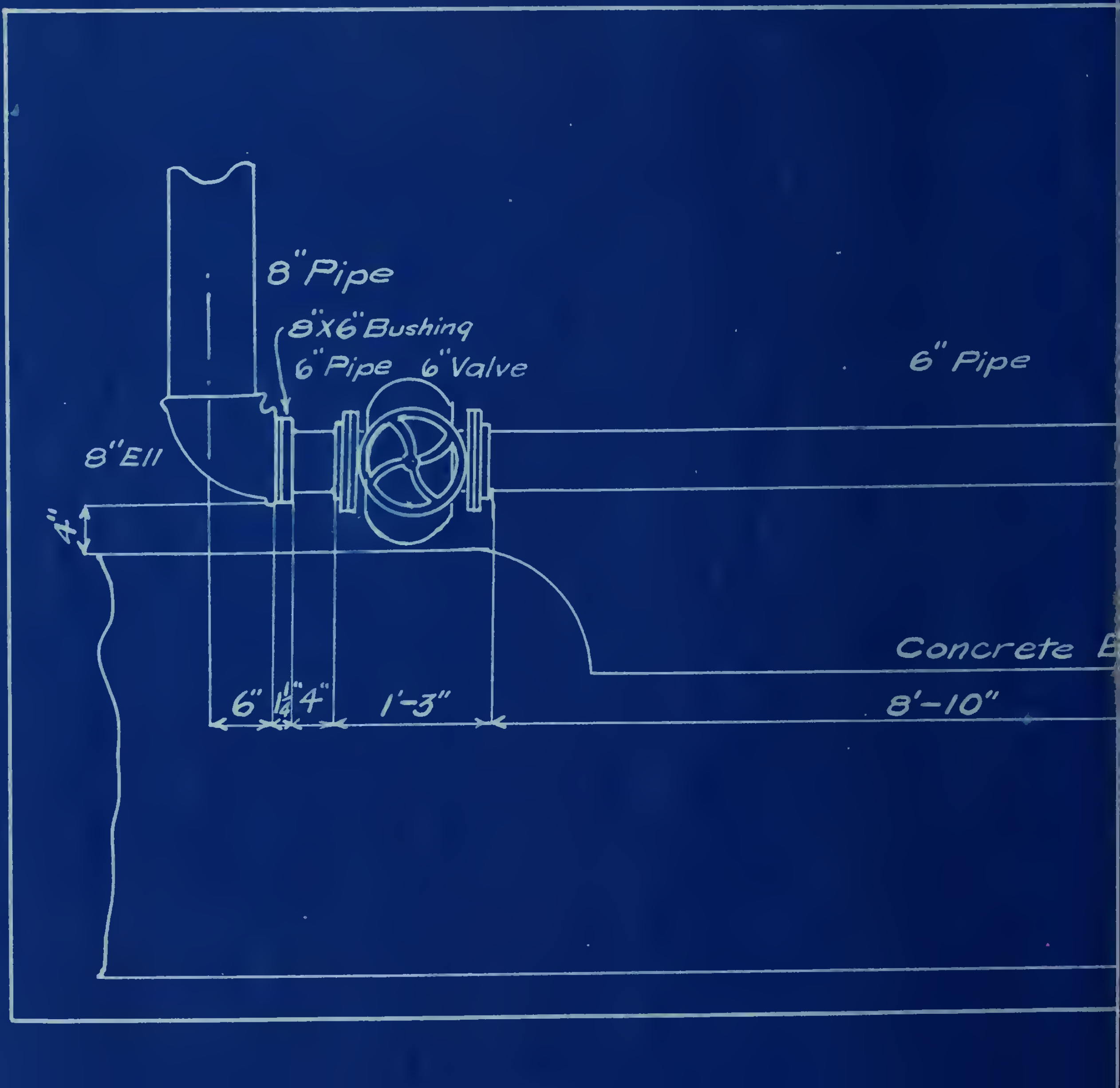


Nozzle Piezometer with Gage Attached.

Nozzle Piezometer in Use.



Method of Applying Piezometer to Nozzle.


8" Pipe
8"X6" Bushing
6" Pipe
6" Valve
6" Pipe
8" Ell
4"
Concrete B
6"
1¼"
4"
1'-3"
8'-10"

PIPE CONNECTIONS
FOR
TESTS ON AMERICAN NOZZLE PIEZOMETER

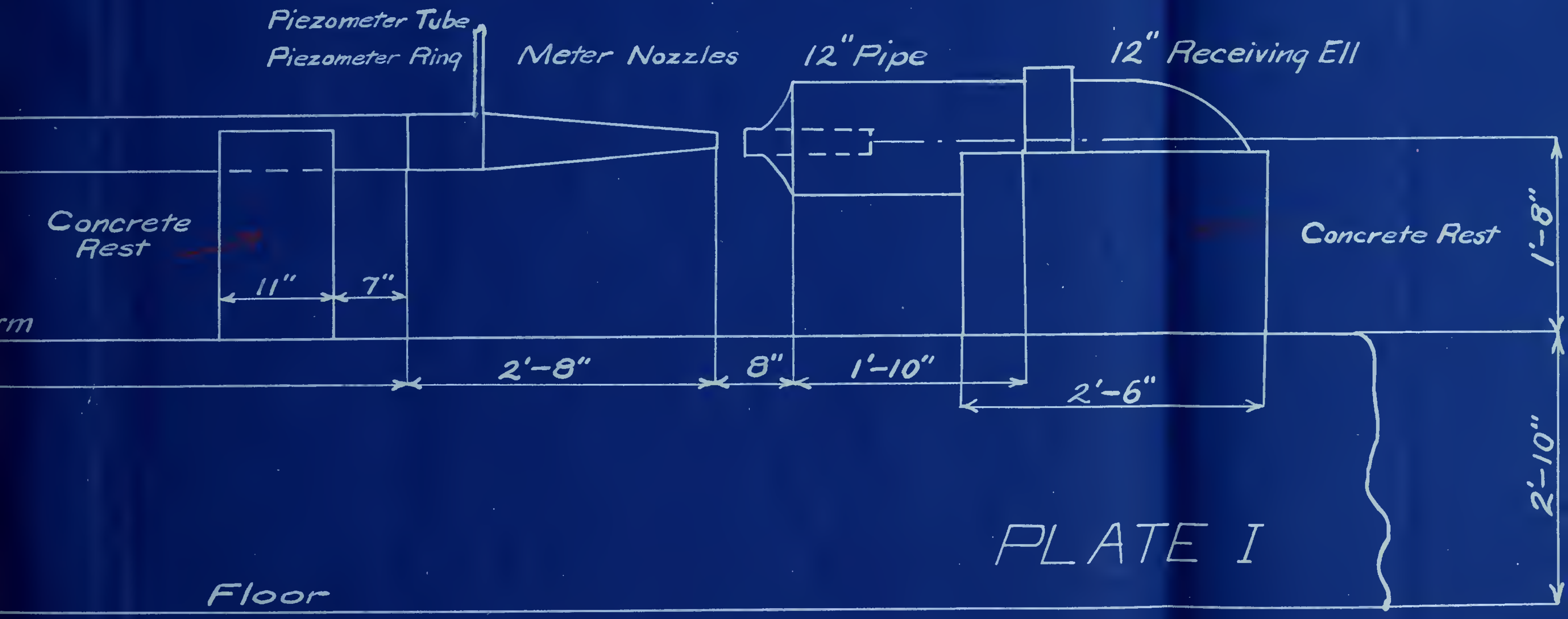


PLATE I

PIPE CONNECTIONS
FOR
TESTS ON AMERICAN NOZZLE PIEZOMETER

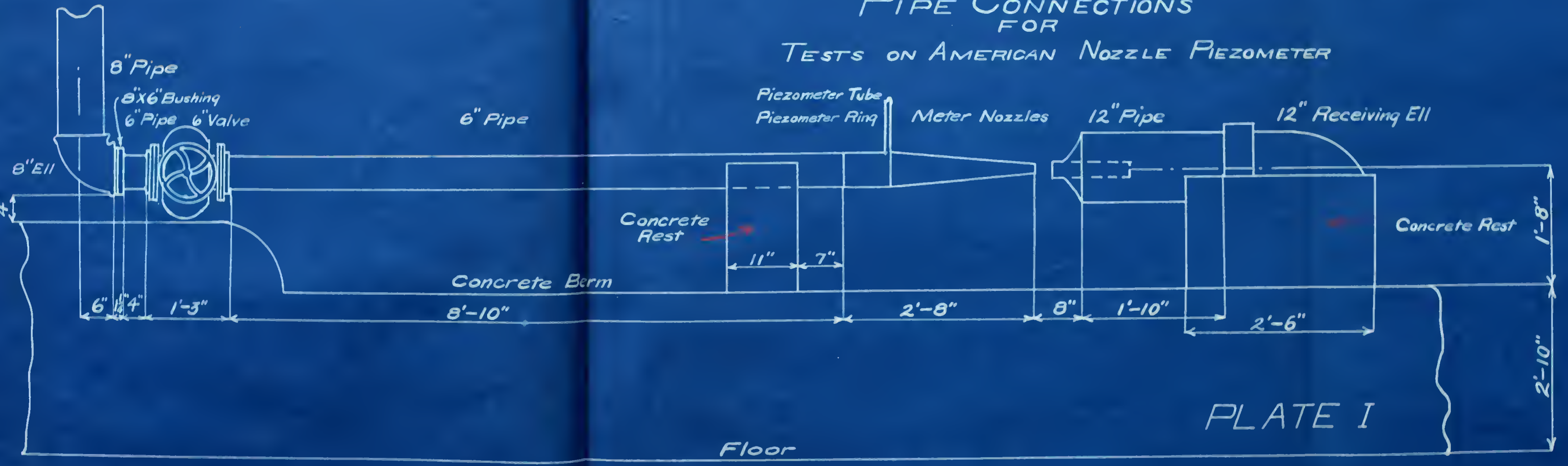


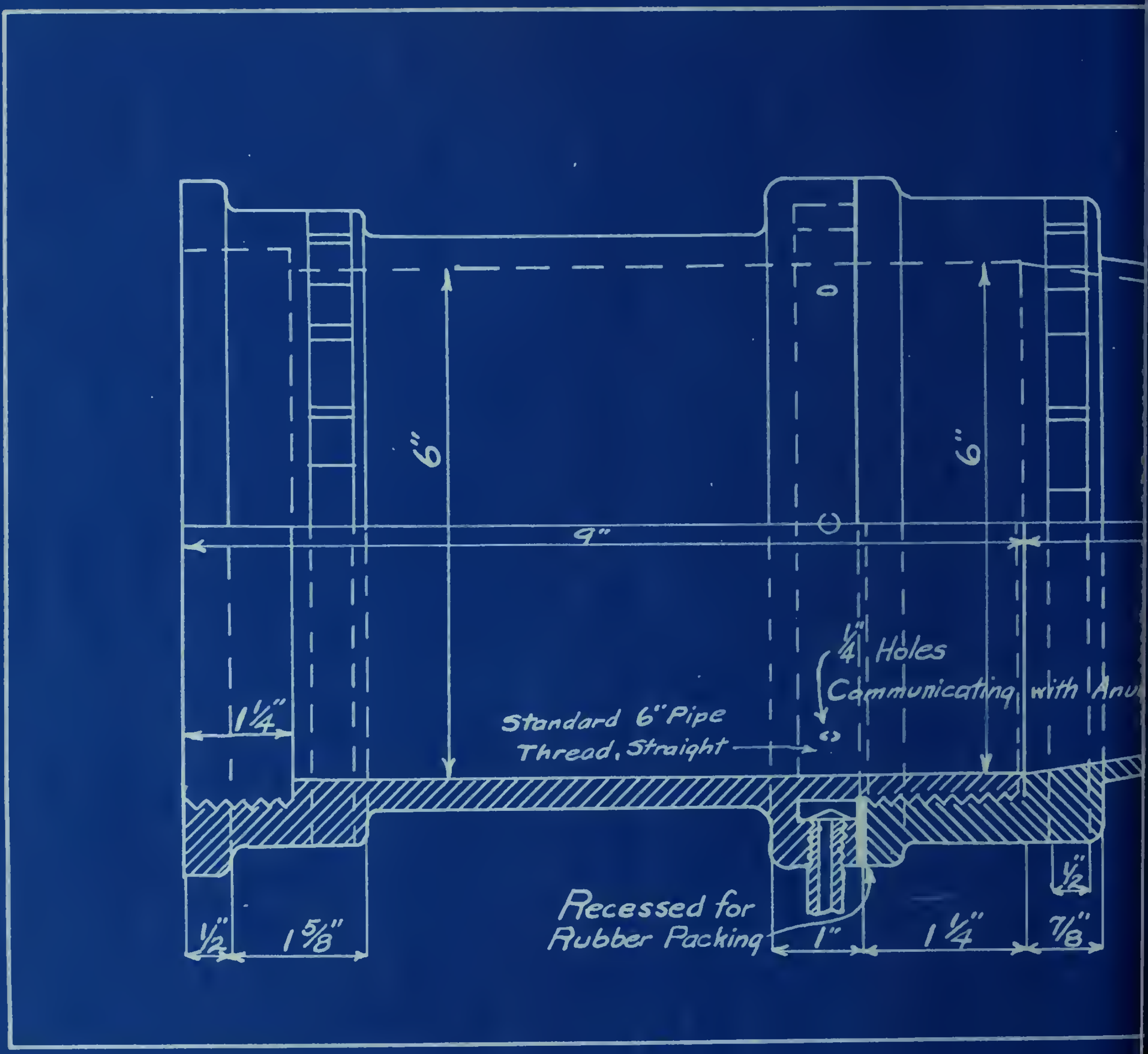
PLATE I

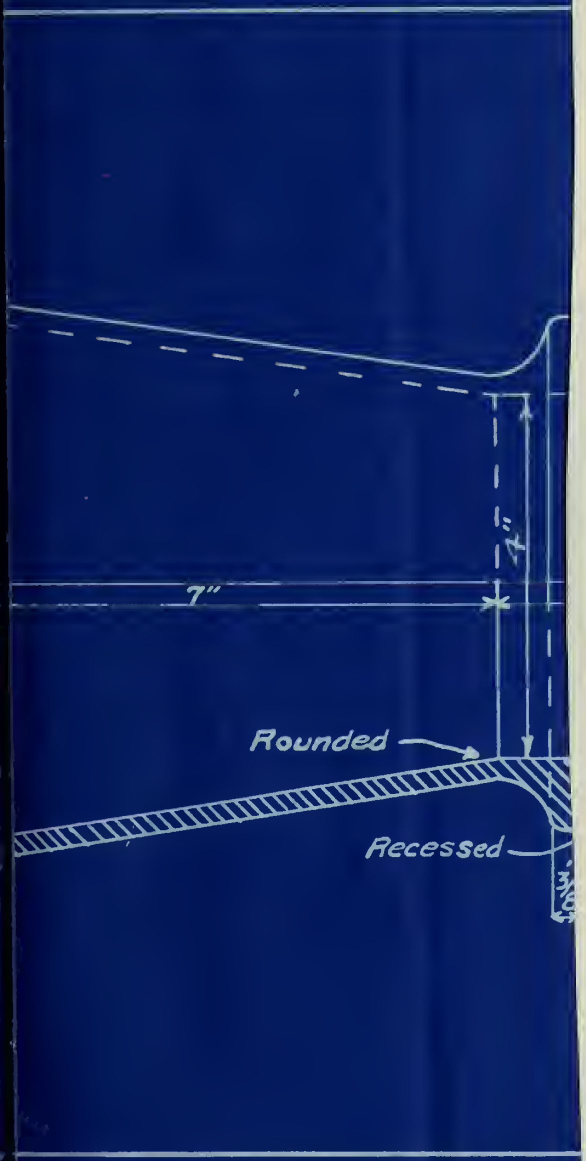
ring, were meter testing nozzles of 1/2-,1-,2-, and 4-inch sizes, made by the Hersey Manufacturing Company, of South Boston, Mass. For dimensions and details see Plate II. The position of the nozzles and actual use is also shown by the photographs on pages 5, 6, and 7.

Much trouble was at first encountered in providing a means for the removal of the water discharged from the nozzle, because of the great volume and dynamic pressure. The receiving elbow shown in accompaning photographs,was the final solution of this difficulty. The elbow was imbedded in concrete and was fastened to the discharge pipe by two tie-rods which were provided with turn-buckles. During the early tests back flow in the elbow was troublesome, especially when using the 2- and 4-inch nozzles, and it became necessary to plan some way to obviate this trouble. For this purpose an adjustable shield was made. For description and detail of this tube see thesis of Messrs. Hiveley and Baldwin.

The water pressure available at nozzles was measured at piezometer ring which is shown in Plate II as a part of the meter testing nozzles. The pressure was transmitted to the mercury and water columns by an overhead piping system made up of quarter inch pipe. As there was in the laboratory equipment no mercury and water columns suitable for recording high heads it was necessary to design an outfit for this purpose. It was decided to make this piece of apparatus not only serviceable for our immediate tests but suitable for a part of the regular laboratory equipment. Therefore considerable care and time was given both to the planning the design and in attending to the construction. Complete description is given below so it may serve for duplicating the apparatus in case it is desired.

This scale was made of well seasoned white pine carefully selected, as it was important that the scale should not warp or crack


6"
6"
9"
¼" Holes
Communicating with Anu
Standard 6" Pipe
Thread, Straight
1¼"
Recessed for
Rubber Packing
½"
1⅝"
1"
1¼"
⅞"
½"


4"
7"
Rounded
Recessed
3/8

METER TESTING NOZZLES

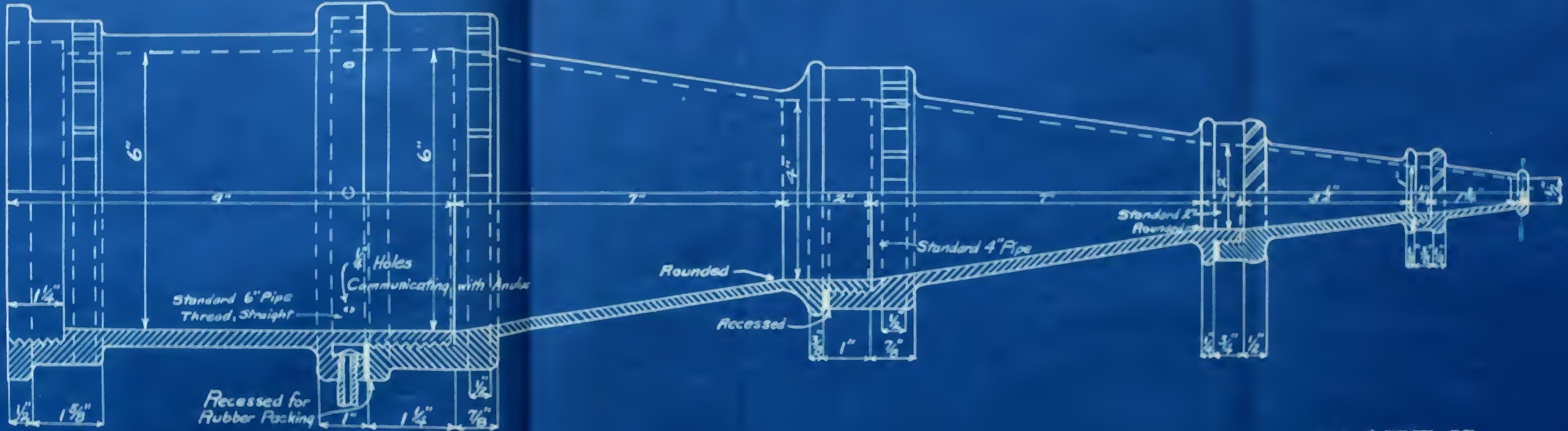
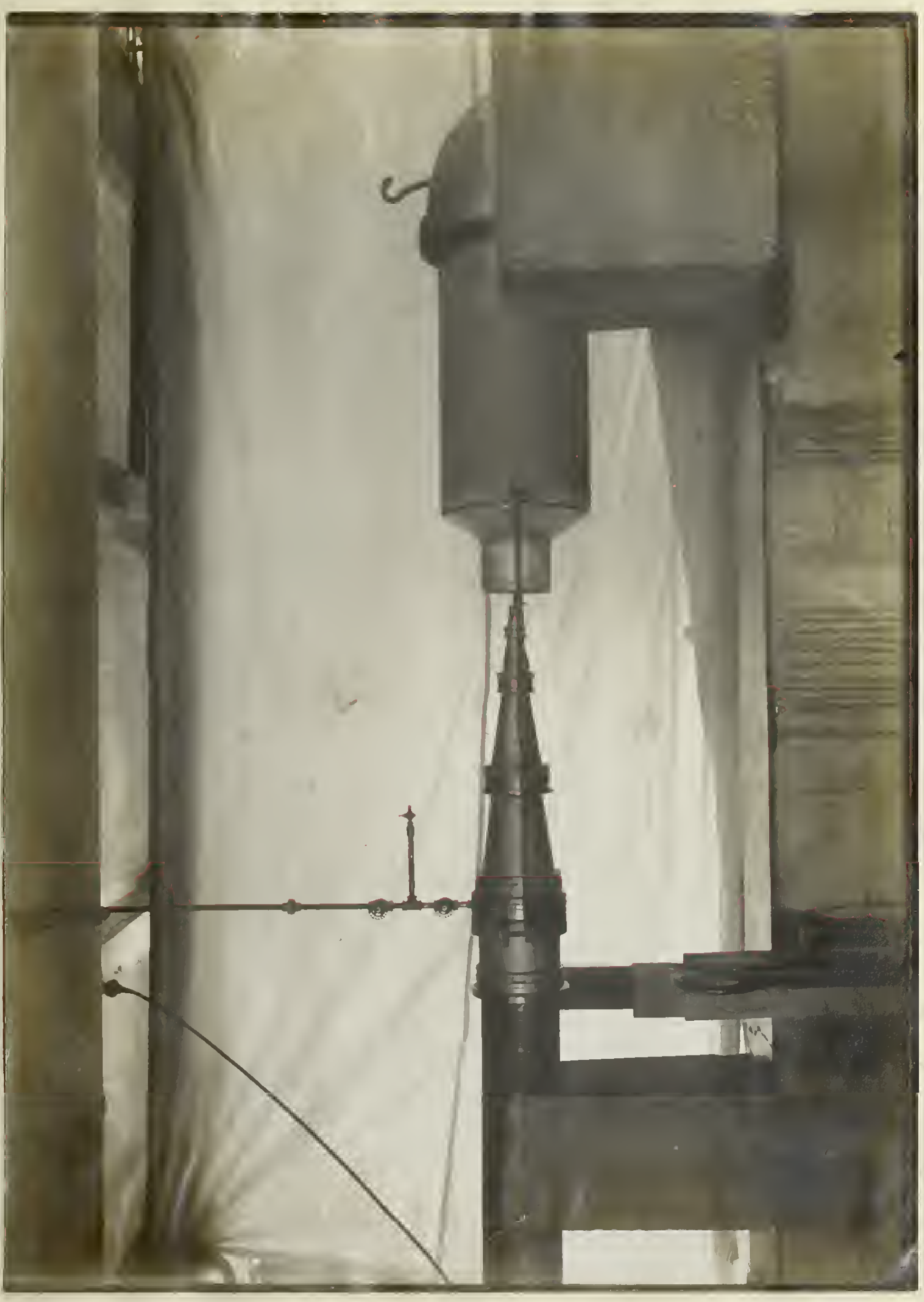
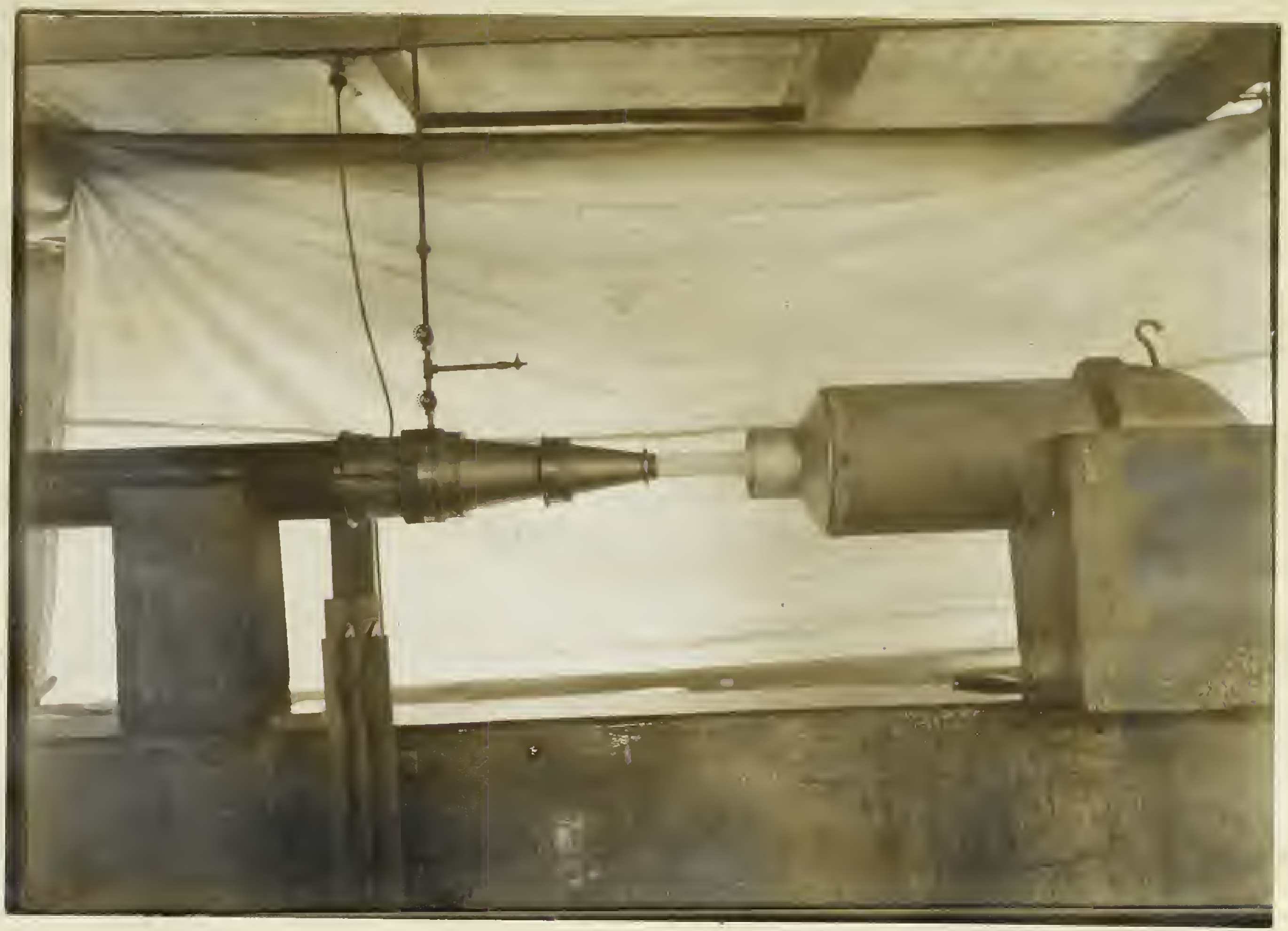


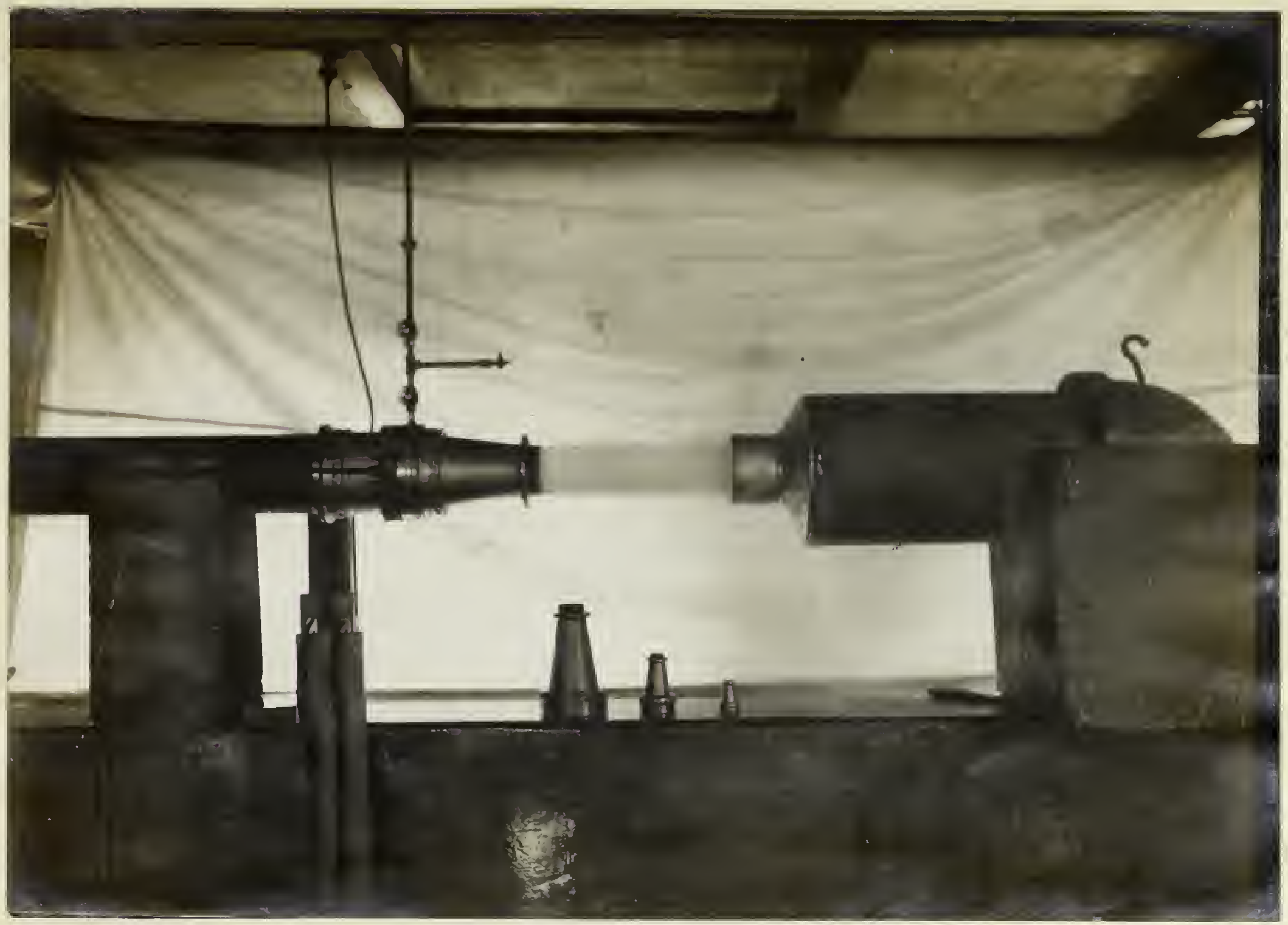
PLATE II



Meter Nozzles with Connections.



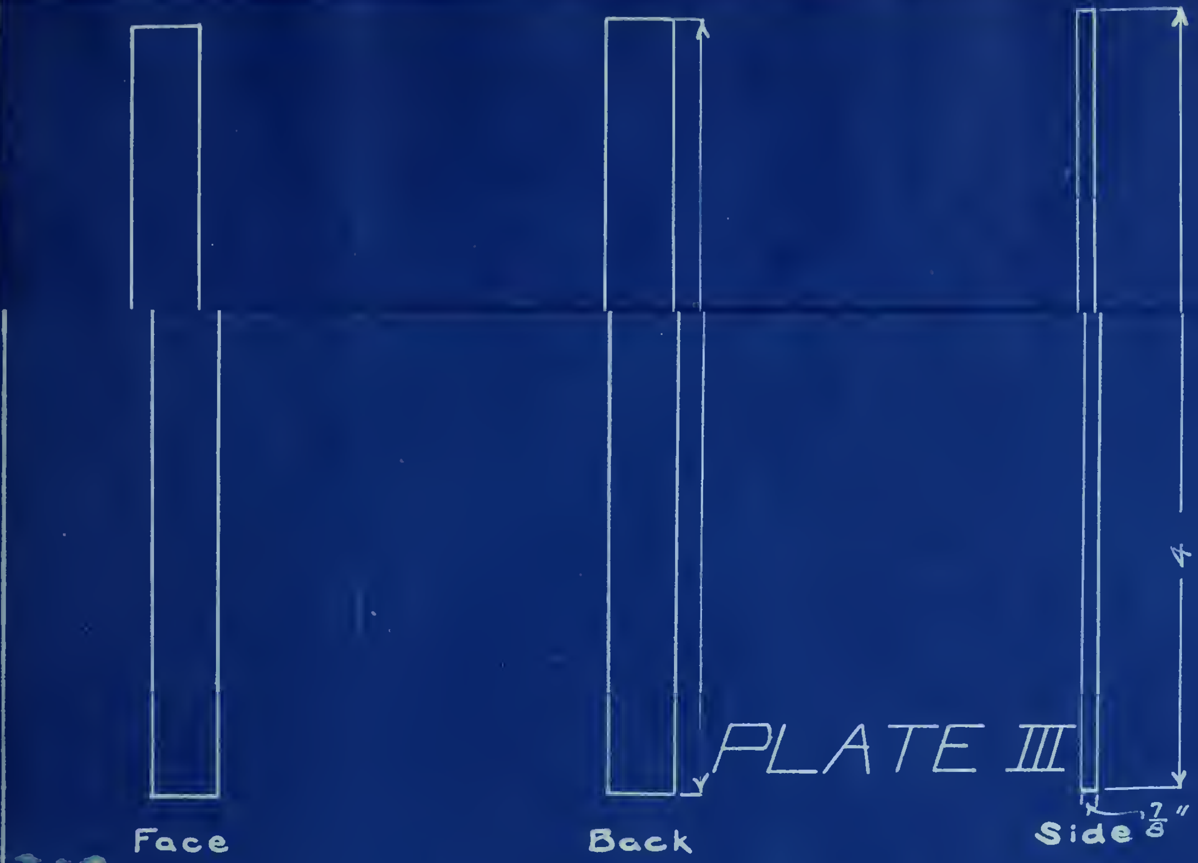
Showing 2 Inch Nozzle Discharging.



Showing 4 Inch Nozzle Discharging.

The wood was free from knots and in total length of 20 feet one joint was allowed. On the back was a two and a half inch strip which served as a stiffener. Dimensions and details are given by Plate III. After joining it was planed to a very smooth surface and then five coats of white paint and two coats of enamel were put on. The graduations were first painted on by an ordinary painter and although he was urged to take great pains, the graduations when finished looked ragged and irregular. This fact is mentioned to show that it is difficult to get good graduations by ordinary painting. The second time we put on graduations ourselves with India ink and a right line pen. Then paper figures were used to mark the feet and tenths divisions and the face of the board was varnished over to make ink and paper waterproof. For detail of face see page 9. The glass tubing used was of 1/4 inch diameter and tested to stand a pressure of 165 pounds. A hand hydraulic pump was used for this testing. As it was difficult to obtain any glass tubing in 20 foot lengths it was necessary to use three lengths of 6 1/2 feet each. The next problem was, suitable connections for the tubing; pieces of heavy canvas lined rubber tubing was used and shellaced to the glass and then fastened with wire, these joints would easily stand as high a pressure as the glass. Shellac was also used in fastening the glass tubing in the mercury pot. At the top, the scale was fastened to the roof truss and at the bottom the mercury pot, as shown in the photograph on page 10. The mercury pot rested on a shelf which was fastened to one of the basement posts.

PLATE III



DESIGN OF SCALE FOR MERCURY AND WATER COLUMNS

Scale 1"=1'

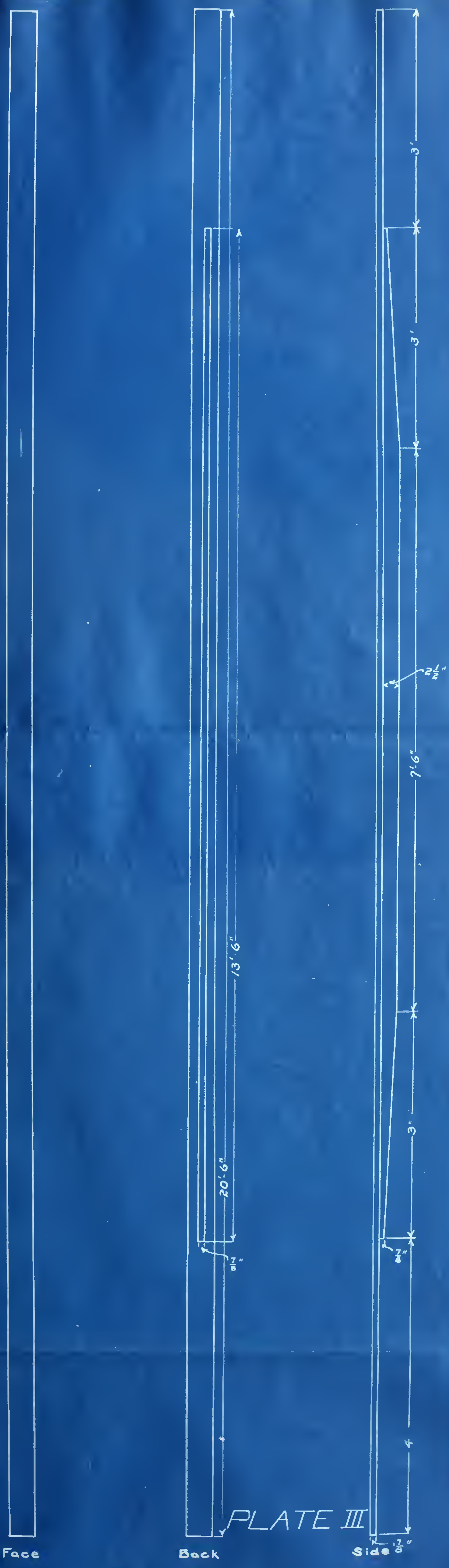


PLATE III

DESIGN OF SCALE
FOR
MERCURY AND WATER COLUMNS
Scale 1"=1'

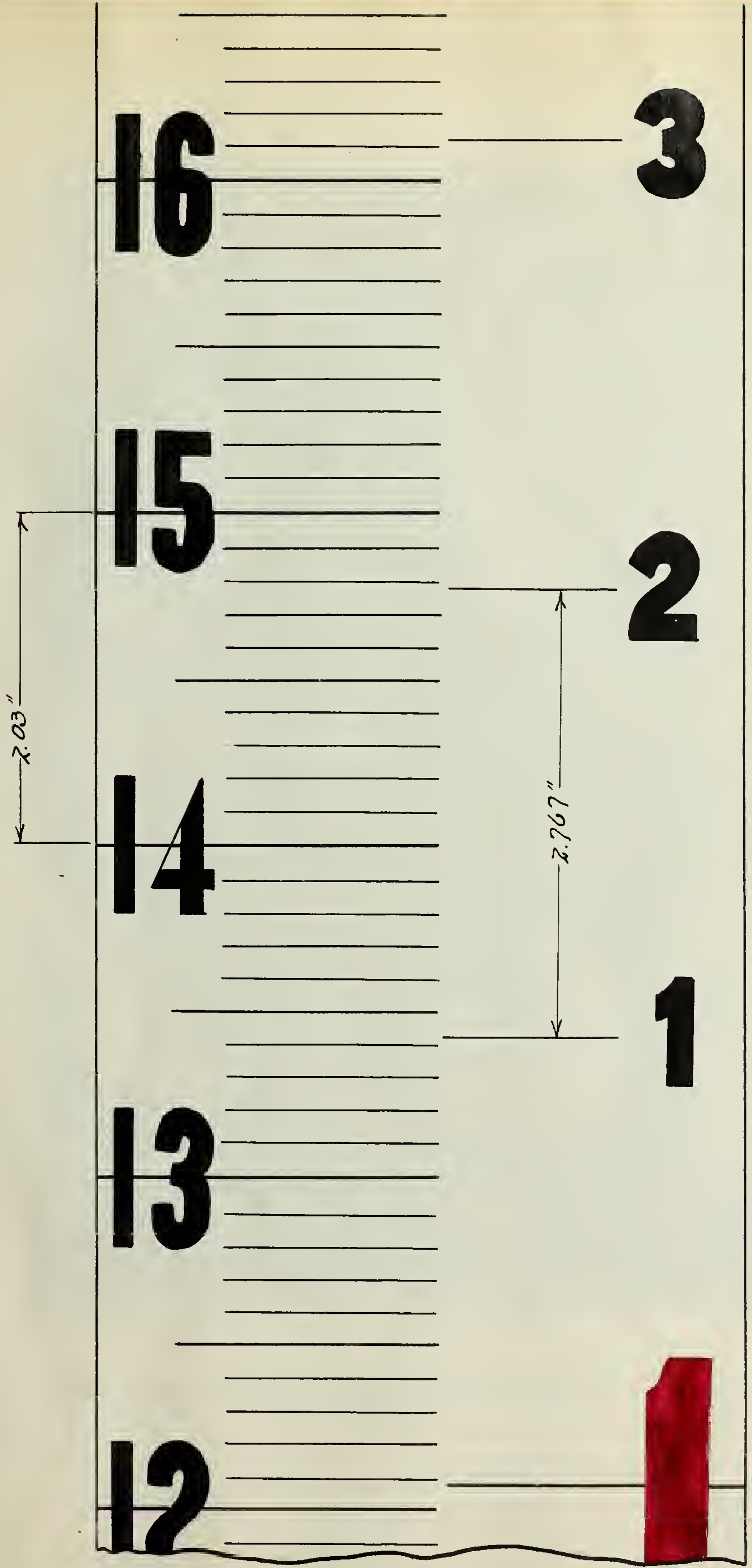
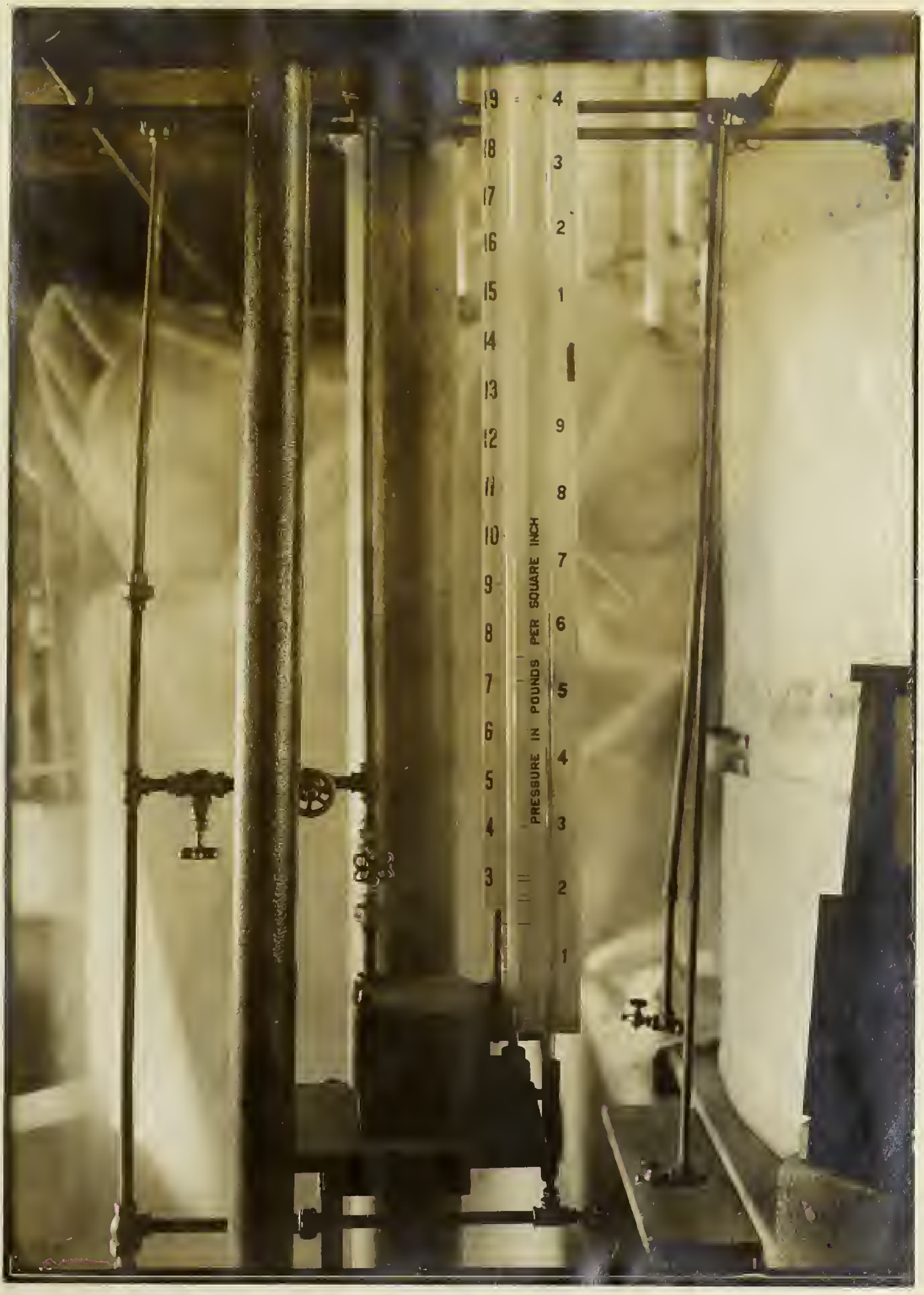


PLATE IV

Detail of Scale for Mercury and Water Columns. Scale 1" = 1"



Showing Scale and Mercury-Pot Connections.

THEORY AND METHOD.

The theory of the nozzle piezometer is that the head at the mouth of the nozzle is equal to the head at the piezometer plus the head due to the velocity of the water through the piezometer ring and the nozzle.

There are two ways of testing the nozzle piezometer, one, by comparison of the pressure indicated by the nozzle piezometer held at the mouth of the nozzle with that at the piezometer ring as shown on the mercury column, and the other by comparison of the pressure transmitted to the mercury column through the cut-water of the nozzle piezometer and that at the piezometer ring.

OPERATION AND DISCUSSION OF TESTS.

First the nozzles were calibrated by means of plugs and micrometers. The results are shown below,

Commercial Size Inches.	Actual Size Inches.	Actual Area Square inches.	% of error in area percent.
1/2 = 0.500	0.500	0.1964	0
1 = 1.000	0.998	0.7822	.4
2 = 2.000	1.999	3.1385	.1
4 = 4.000	3.998	12.5540	.1

The errors in area are too small to be considered so the nominal sizes were used in all computations.

At the start of these tests it was thought that water flowing over a weir could be measured accurately enough but the results obtained this way were of no value. Even the results obtained from the pit measurements were not as good as w~~sh~~ould be expected. The work was gone over several times and checked but the results still

remained the same. The error was probably in ~~the calibration~~ leakage of the measuring pit which was ~~done~~ calibrated by Messrs. Jones and Korsmo who had a thesis in which the measuring pit was also used. If more time could have been spent on this part of the work we have no doubt that the error could be located and corrected.

To prove that pressures at the piezometer ring correspond to the theoretical discharge given by the formula,

$$q = 29.83\ D^2\sqrt{\frac{P_1}{(1/c)^2 - (D/d)^4}}$$

the nozzles were discharged into the measuring pit.

In order to get accurate results in flow in the pit must get total flow during given time, and also accurate method of measuring time of flow. In order to get total flow in the pit the calibration as already referred to was taken, and a curve was drawn to show this calibration graphically. With hook gage readings taken at time of starting and time of stopping the flow, the quantity discharged could be figured directly. This was compared to quantity obtained by using pressure shown on mercury or water columns. With these two values could get percentage of regisration of scale or gauge. The time was accurately obtained by use of stop watch. As soon as the valve was opened, which only took a fraction of a second, the watch was snapped and left running until the pit was nearly full, when the valve was closed and watch snapped again, then read the elapsed time.

In the above formula,

q = discharge in gallons per minute

D = diameter of nozzle in inches.

P_1 = pressure at piezometer ring in pounds per square inch.

c = coefficient of discharge.

d = diameter of entrance pipe in inches.

In this experiment d = 6 and let c = .98

Then for 1/2 inch nozzle $q = 7.32\sqrt{P_1}$

1 " " $q = 29.30\sqrt{P_1}$

2 " " $q = 117.00\sqrt{P_1}$

4 " " $q = 474.00\sqrt{P_1}$

The calibration of measuring pit is shown on page 14.

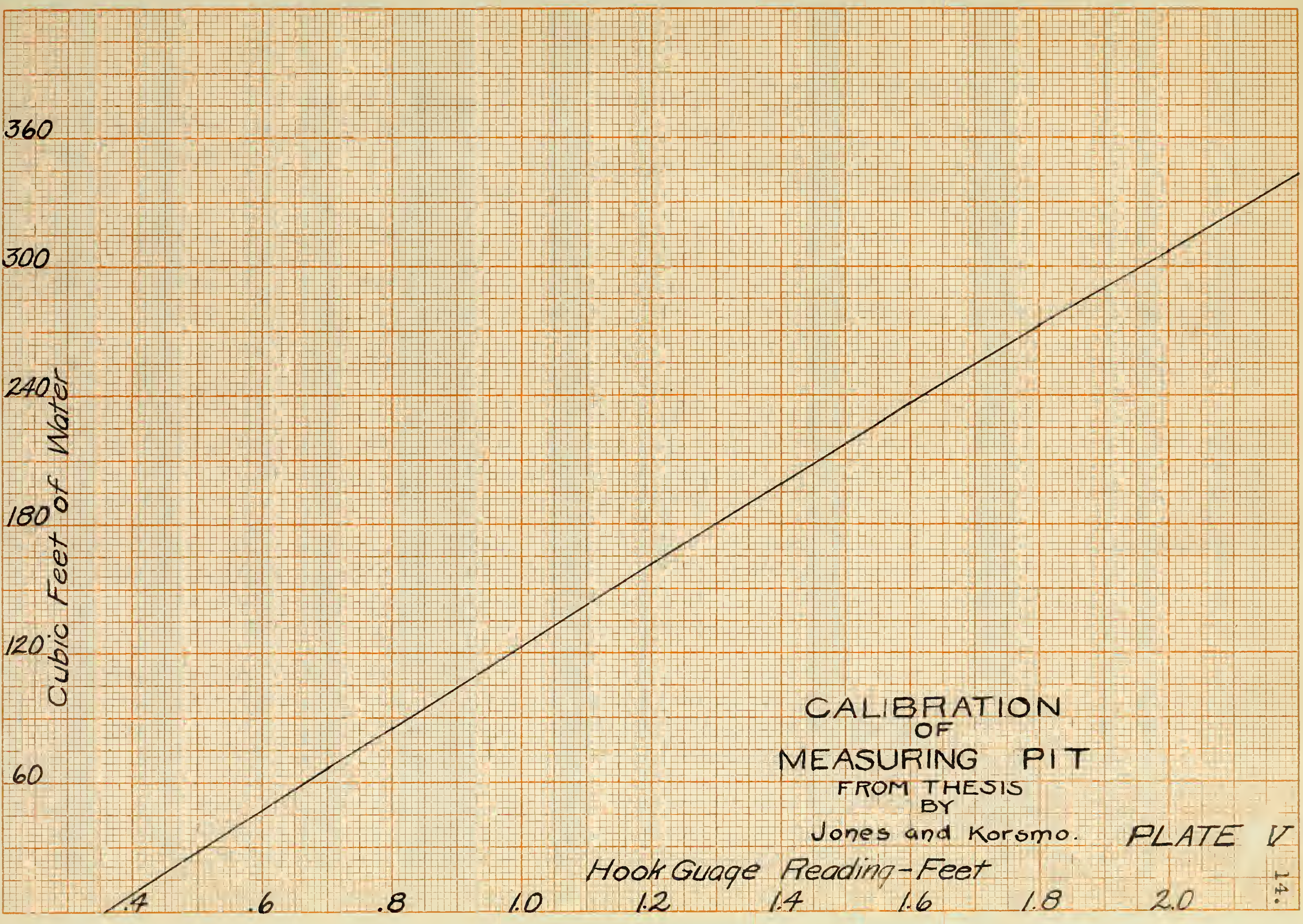
The table on page 15 shows observations and computations for tests 51-60 and 69-82 inclusive, which were tests in which the measuring pit was used. On page 16 is a graph for each nozzle, showing relation of theoretical to actual discharge under known pressures at piezometer ring.

It might be mentioned here that due either, to the whirling of the water in the 8-inch ell of the approach pipe, or to slight imperfections in the reaming out the nozzles, there was a marked twisting motion of the stream as it was discharged from the nozzle, but this we do not think effected our results at all.

Although these experiments are not consistent and regular, yet the average of 100 percent justifies us in believing in the correctness of the formula for discharge as given on page 12.

The calibrations of the gages used on nozzle piezometer, with date of each calibration are shown on pages 17 and 18.

The first real tests of the nozzle piezometer were those which compared its readings at the mouth of the nozzle to those of the mercury column connected to the piezometer ring. The comparison was of the quantities of discharge given by the formulas for the piezometer and the piezometer ring.



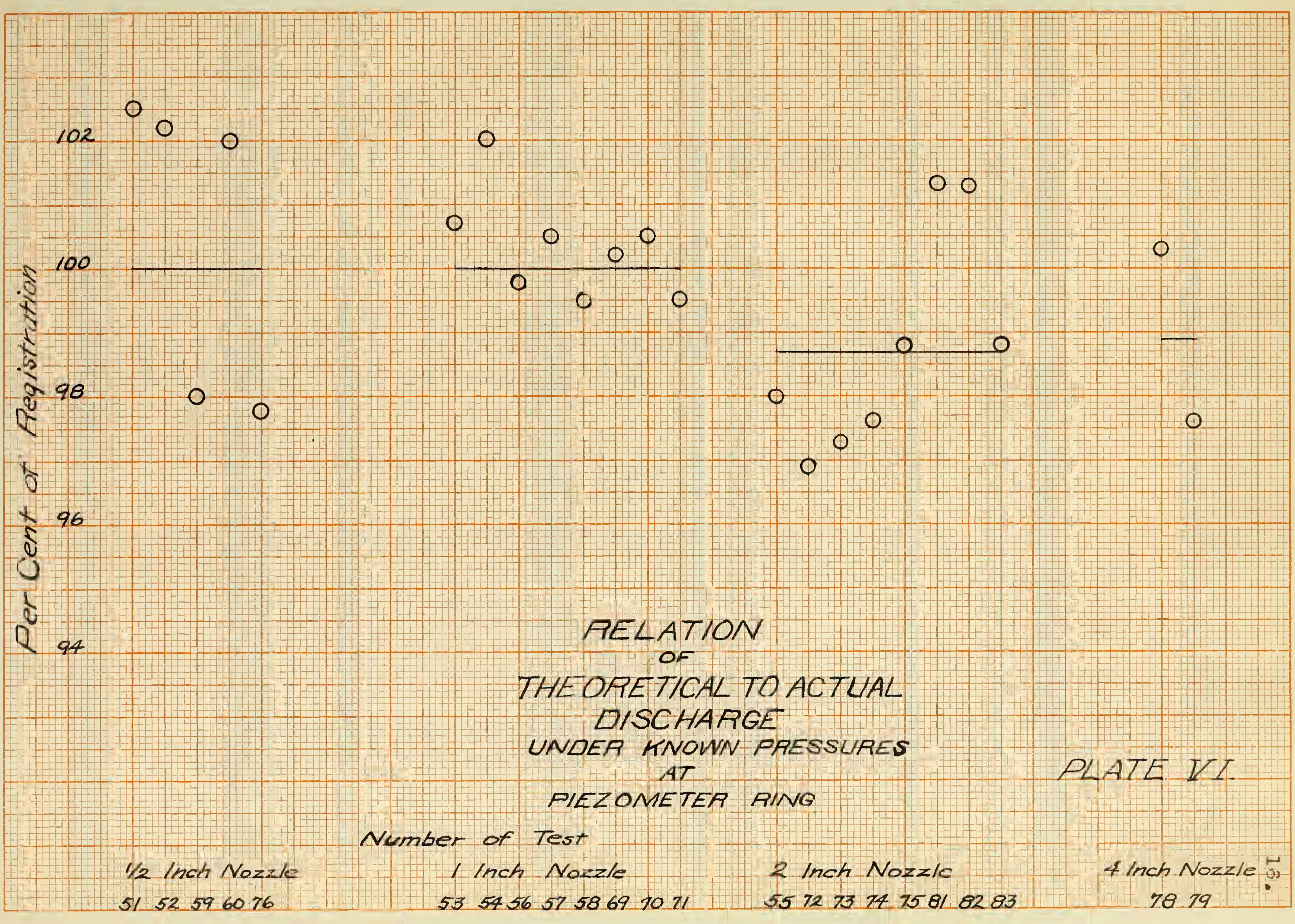
CALIBRATION
OF
MEASURING PIT
FROM THESIS
BY
Jones and Korsmo.

PLATE V

U. OF I. S. S. FORM 3

TABLE I.

Test No.	Date	Time H-M-S	Nozzle Diameter In.	Nozzle Area Sq.in.	Pressure at Piezometer Ring Lb/sq.in.	Pit Readings Zero Reading Ft.	Pit Readings Discharge Reading. Ft.	Quantity Flowing measured by Pit Gal/min.	Quantity Flowing measured by Formula Gal./min.	Per Cent of Regisration of Actual Quantity	Remarks.
51	Mar.27	-30-	1/2	.1964	15.4	.460	1.069	27.9	28.7	102.5	Setting hook gauge while nozzles are discharging, using ordinary watch.
52	"	-15-	1/2	"	23.9	1.435	1.834	34.9	35.7	102.2	
53	"	-10-	1	.7854	10.15	.513	1.203	94.0	93.3	100.7	
54	"	-10-	1	"	25.1	.885	1.975	143.0	146.0	102.0	
55	"	-3 56	2	3.1416	8.9	.747	1.800	356.0	349.0	98.0	
56	"	-8-	1	.7854	25.4	.714	1.600	148.0	147.5	99.8	
57	"	-6 20	1	"	50.6	.654	1.640	207.0	208.0	100.5	"
58	"	-3 40	1	"	37.4	.686	1.245	180.0	179.0	99.5	"
59	Apr.21	-9 55	1/2	.1964	19.8	.952	1.200	33.2	32.5	98.0	Time between opening and closing of valve caugt with stop watch.
60	"	-14 52	1/2	"	9.25	1.209	1.443	21.7	22.2	102.0	
69	Apr.22	-16 56	1	.7854	19.21	.4965	2.126	128.2	128.4	100.2	
70	"	-16 4	1	"	17.88	.5190	2.014	123.0	123.8	100.5	
71	"	-20 10	1	"	830	.652	1.941	85.0	84.5	99.5	
72	May 4	-2 59	2	3.1416	16.07	1.085	2.192	485.0	469.5	96.9	"
73	"	-2 35	2	"	19.63	1.050	2.103	534.0	519.0	97.3	"
74	"	-5 7	2	"	6.42	.903	2.073	303.5	296.5	97.6	"
75	"	-3 15	2	"	12.42	1.068	2.100	419.0	413.0	98.8	"
76	May 6	-25 56	1/2	.1964	23.12	.988	1.691	36.0	35.2	97.8	"
77	"	-27 34	1/2	"	23.93	.885	1.684	38.8	35.8	92.6	"
78	May 11	- - 47	4	12.5664	10.41	.708	1.600	1525.0	1530	100.3	"
79	"	- - 52	4	"	8.65	.830	1.795	1430.0	1393	97.6	"
80	"	- - 56	4	"	7.75	.713	1.784	1472.0	1320	90.0	"
81	"	-2 50	2	3.1416	20.7	.702	1.866	525.0	532	101.3	"
82	"	-2 32	2	"	20.7	.721	1.745	525.0	532	101.3	"
83	"	-3 19	2	"	18.3	.632	1.890	507.0	500	98.8	"



RELATION
OF
THEORETICAL TO ACTUAL
DISCHARGE
UNDER KNOWN PRESSURES
AT
PIEZOMETER RING

PLATE VI.

U. OF I. S. S. FORM 3

TABLE II

CALIBRATION OF GAUGES

Date - Mar. 6, 1909.

Gauge No. 83.

Tester Reading	Gauge Reading
Going up	
0.0	-0.5
5	4.25
10	9.0
15	14.0
20	18.5
25	23.5
30	28.75
35	33.25
40	38.25
45	43.0
50	48.5
55	53.5
60	59.0
65	63.5
70	68.75
75	74.0
80	79.0
85	84.25
90	89.50
95	94.50
100	99.50
105	105.0
110	109.75
Going down	
110	109.75
100	100.0
90	90.0
80	79.5
70	69.25
60	59.50
50	49.0
40	39.0
30	29.0
20	18.75
10	9.75
0	-0.5

Gauge No. 28.

Tester Reading	Gauge Reading
Going up	
0	+1.0
5	5.25
10	10.25
15	15.0
20	20.0
25	25.0
30	30.0
35	35.0
40	40.0
45	45.0
50	49.5
55	54.5
60	59.0
65	64.0
70	68.5
75	73.25
80	78.25
85	83.25
90	88.25
95	93.25
100	98.75
Going down	
100	98.75
90	89.0
80	78.5
70	68.5
60	59.0
50	50.0
40	40.5
30	30.0
20	20.0
10	10.0
0	0

TABLE III

CALIBRATION OF GAUGES

Date - Mar. 20, 1909.

Gauge No. 83.

Tester Reading	Gauge Reading
0	-.5
10	9.0
50	48.75
100	99.50

Gauge No. 28.

Tester Reading	Gauge Reading
0	+1.0
10	10.25
50	49.50
100	99.00

Date - May 25, 1909.

Gauge No. 83.

Tester Reading	Gauge Reading
0	-0.5
5	4.7
10	9.2
15	14.0
20	18.8
25	23.8

Gauge No. 28.

Tester Reading	Gauge Reading
0	+1.0
5	6.0
10	11.5
15	16.0
20	20.5
25	25.5

For the piezometer,

$$Q = A \times 37.2248 \sqrt{P}$$

where Q = quantity in gallons per minute.
A = area of nozzle in square inches.
P = pressure at mouth of nozzle in pounds per sq. in.
and $c = .98$ = coefficient of discharge.

which formula takes the form

for 1/2 inch nozzle, $Q = 7.309 \sqrt{P}$
1 " " $Q = 29.236 \sqrt{P}$
2 " " $Q = 116.945 \sqrt{P}$
4 " " $Q = 467.730 \sqrt{P}$

For the piezometer ring ,

$$q = 29.83 D^2 \sqrt{\frac{P_1}{(1/c)^2 - (D/d)^4}}$$

which formula takes the form

for 1/2 inch nozzle, $q = 7.32 \sqrt{P_1}$
1 " " $q = 29.30 \sqrt{P_1}$
2 " " $q = 117.00 \sqrt{P_1}$
4 " " $q = 474.00 \sqrt{P_1}$

The comparison then is of the quantities Q of gage and q of the piezometer ring, and the percentage of regisration is the ratio of Q to q expressed in per cent.

Table IV on page 20 gives all data for tests when piezometer gage and mercury column were used.

TABLE IV.

Test No.	Date	Nozzle Diameter Inches	Piezometer Gauge Readings lbs/sq.in. Actual	Piezometer Gauge Readings lbs/sq.in. Corrected	Pressure at Piezometer Ring from Mercury Column lbs./sq.in.	Discharge gal./min. calculated from Piezometer Gauge	Discharge gal./min. calculated from Piezometer Ring	Per Cent of Regisration
4	Mar. 6	1	22.7	22.7	22.60	139.0	137.0	100.0
8	"	2	20.5	21.8	21.00	546.0	537.0	101.5
12	Mar. 12	1	13.0	12.8	12.70	104.5	104.5	100.1
16	"	1	6.5	6.25	6.64	73.0	75.5	96.8
24	"	2	5.8	6.5	6.42	298.0	297.0	100.3
25	"	1	64.0	65.0	66.0	235.5	237.6	99.3
26	"	2	63.0	64.5	66.30	940.0	953.0	98.7
30	Mar. 20	1/2	25.0	25.0	25.10	36.5	36.6	99.7
34	"	1/2	16.25	16.25	16.30	29.4	29.5	99.7
38	"	1/2	6.0	5.75	5.60	17.5	17.3	100.1
42	"	2	10.3	11.30	11.30	393.0	393.0	100.0
46	"	4	13.0	14.0	13.00	1750.0	1710.0	102.3
50	"	4	6.75	7.50	7.00	1282.0	1255.0	102.0
87	May 25	1/2	25.8	25.8	25.60	37.2	37.0	100.5
91	"	1/2	18.8	18.8	18.70	31.7	31.6	100.3
95	"	1/2	9.8	9.6	9.70	22.7	22.8	99.9
99	"	1	23.3	23.3	24.70	141.0	145.0	97.4
103	"	1	17.5	17.5	18.00	122.2	124.0	98.7
107	"	1	9.3	9.1	9.30	88.0	89.2	98.7
111	"	2	19.5	21.0	20.60	535.0	530.0	100.9
115	"	2	14.5	15.5	15.30	460.0	457.0	100.5
119	"	2	7.0	8.0	8.40	330.0	339.0	97.5
123	"	4	6.6	7.40	7.00	1273.0	1255.0	101.5
127	"	2	11.0	12.0	12.00	405.0	405.0	100.0

The other part of the test on the nozzle piezometer consist- of a comparison of the pressures at the piezometer ring as shown on mercury column with those transmitted through the cut-water of the nozzle piezometer. The comparisons made were the same as those when the gage was attached. Table V gives all data for this latter test.

Graphs on pages 23, 24, 25 and 26 show relation between discharges calculated from piezometer pressures and piezometer ring pressures for 1/2-, 1-, 2- and 4-inch nozzles respectively.

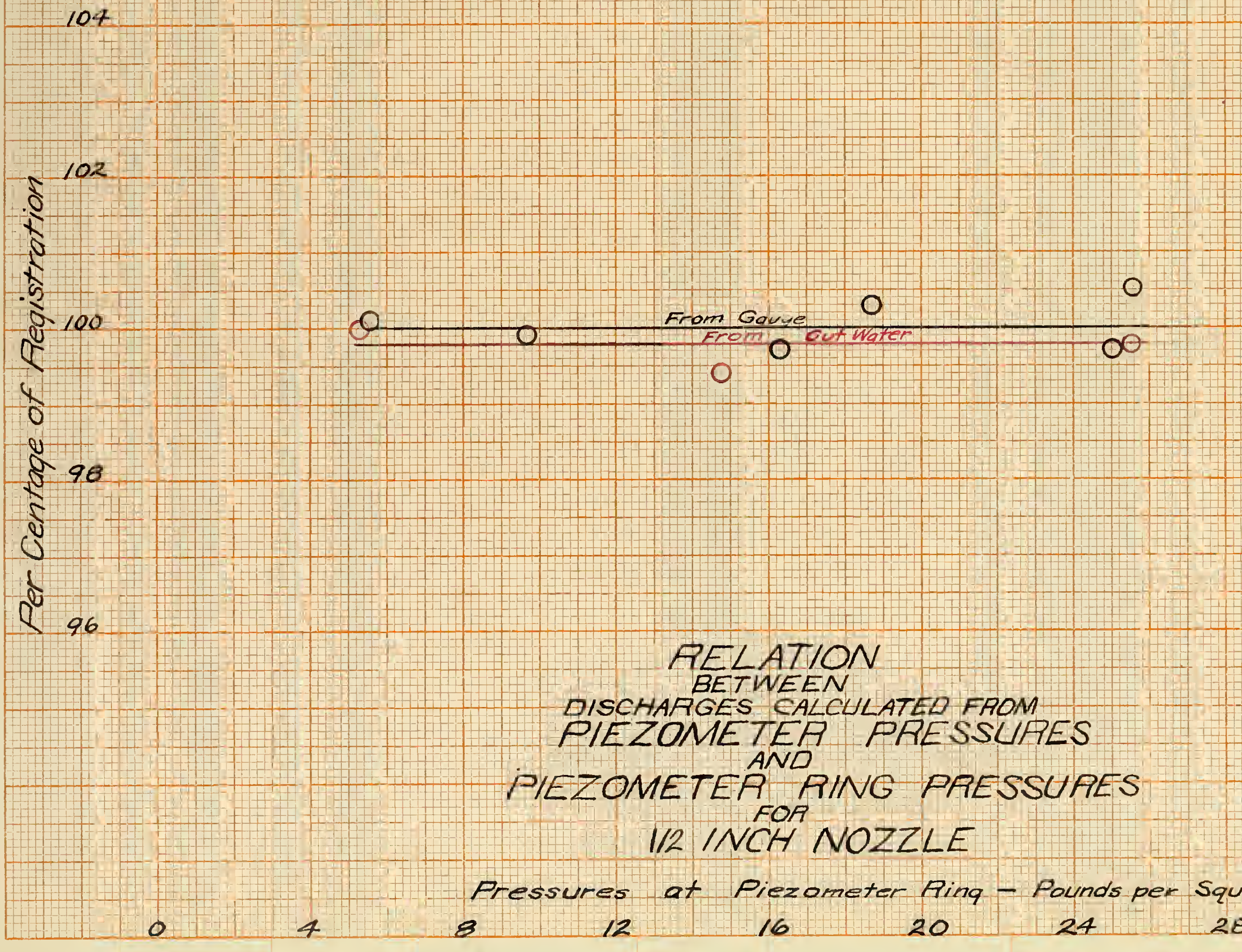
CONCLUSION.

The irregularity of the points on the graphs for pressures under 10 pounds show that the instrument is not accurate below this point. The upper limit of accuracy was not found but the instrument is as accurate for high pressures as the readings can be taken. In all of thes experiments the distance of the cut-water from the end of the nozzle was 3/4 of an inch which distance gives good results. It is not well to put the cut-water closer to the nozzle as it interferes with the flow. Tilting of the shield vertically in the vertical plane of the axis of the nozzle, up to an angle of about 15 degrees with the horizontal, does not effect the reading of the pressure.

Both ~~forms~~ sets of the tests show the American Nozzle Piezometer to be accurate to within 1 percent.

TABLE V.

Test No.	Date	Nozzle Diameter Inches	Cul-water Readings from Mercury Column lbs./sq. in.	Pressure at Piezometer Ring from Mercury Column lbs./sq. in.	Discharge gal./min. from		Per Cent of Regisration
					Cul-water	Piezometer Ring	
124	May 26	1/2	25.35	25.5	36.8	36.9	99.8
125	"	1/2	14.6	14.8	27.9	28.1	99.4
126	"	1/2	5.30	5.3	16.8	16.8	100.0
127	"	1	24.80	25.0	145.5	146.2	99.5
128	"	1	16.10	16.10	117.3	117.5	99.8
129	"	1	7.0	7.10	77.4	78.0	99.2
130	"	2	21.35	21.35	540.0	540.0	100.0
131	"	2	18.00	18.00	496.0	496.0	100.0
132	"	2	11.8	11.7	401.0	400.0	100.3
133	"	4	7.8	7.50	1308.0	1300.0	100.5



RELATION
BETWEEN
DISCHARGES CALCULATED FROM
PIEZOMETER PRESSURES
AND
PIEZOMETER RING PRESSURES
FOR
1/2 INCH NOZZLE

PLATE VII

U. OF I. S. S. FORM 3

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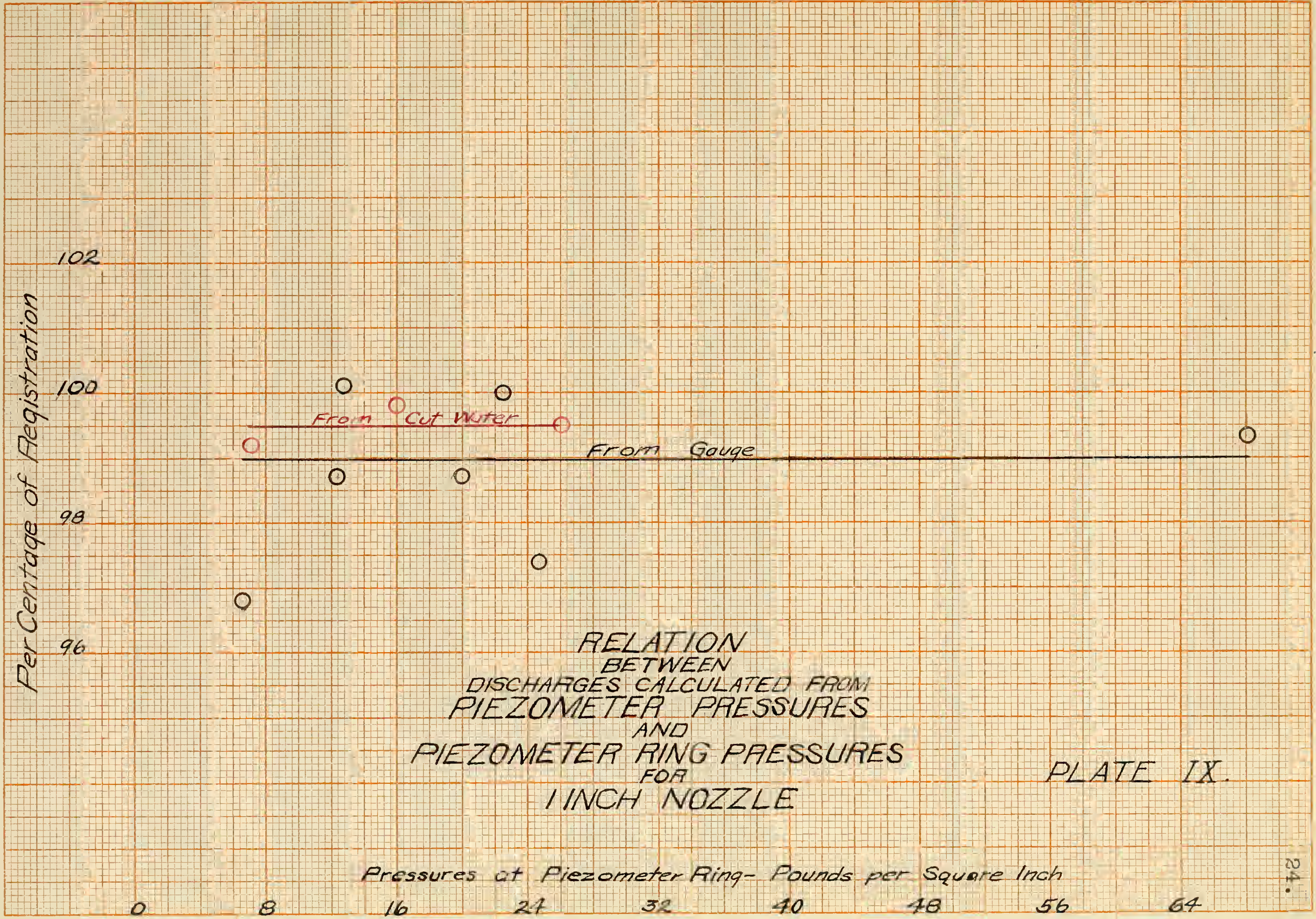
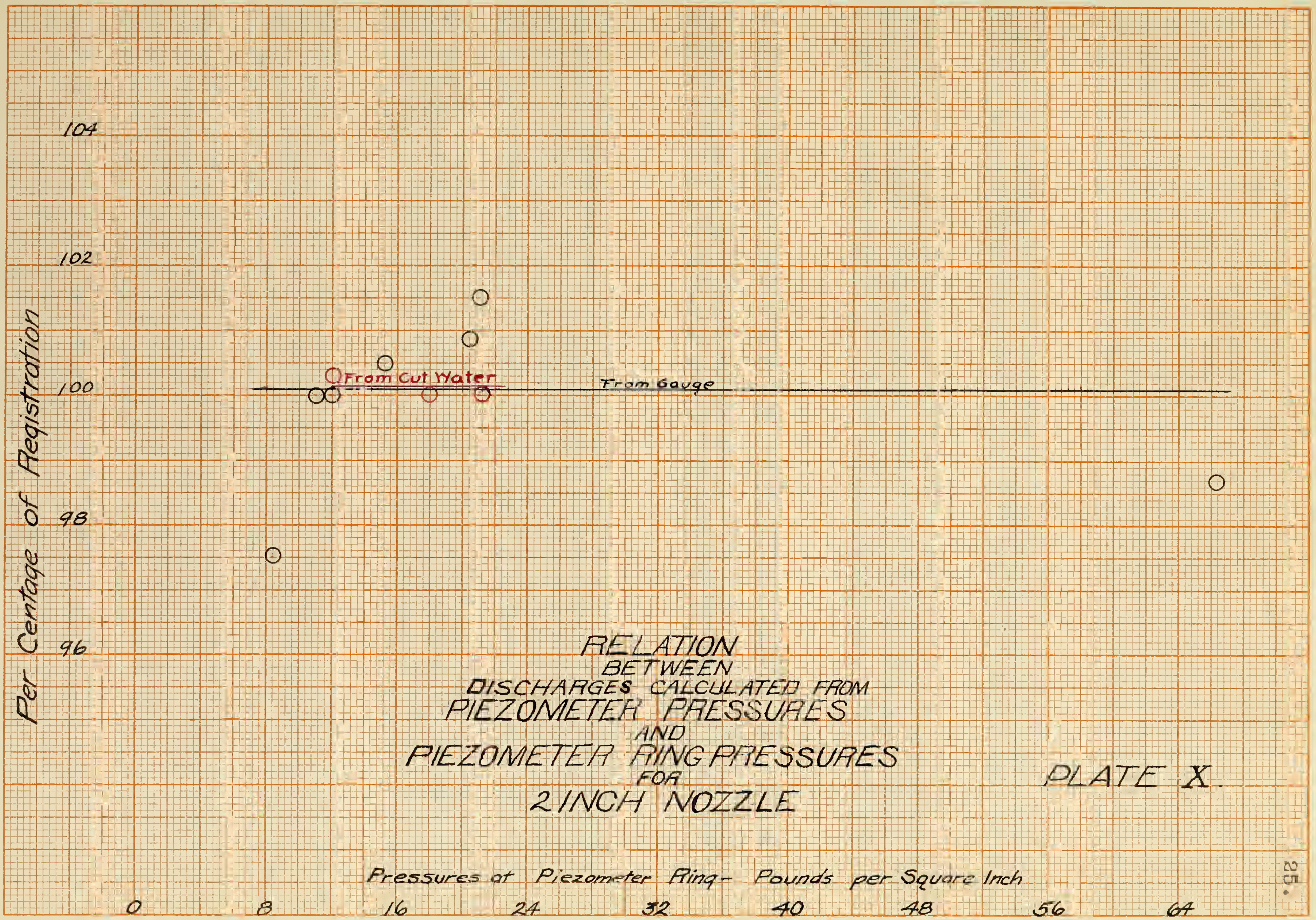


RELATION
BETWEEN
DISCHARGES CALCULATED FROM
PIEZOMETER PRESSURES
AND
PIEZOMETER RING PRESSURES
FOR
1 INCH NOZZLE

PLATE IX.

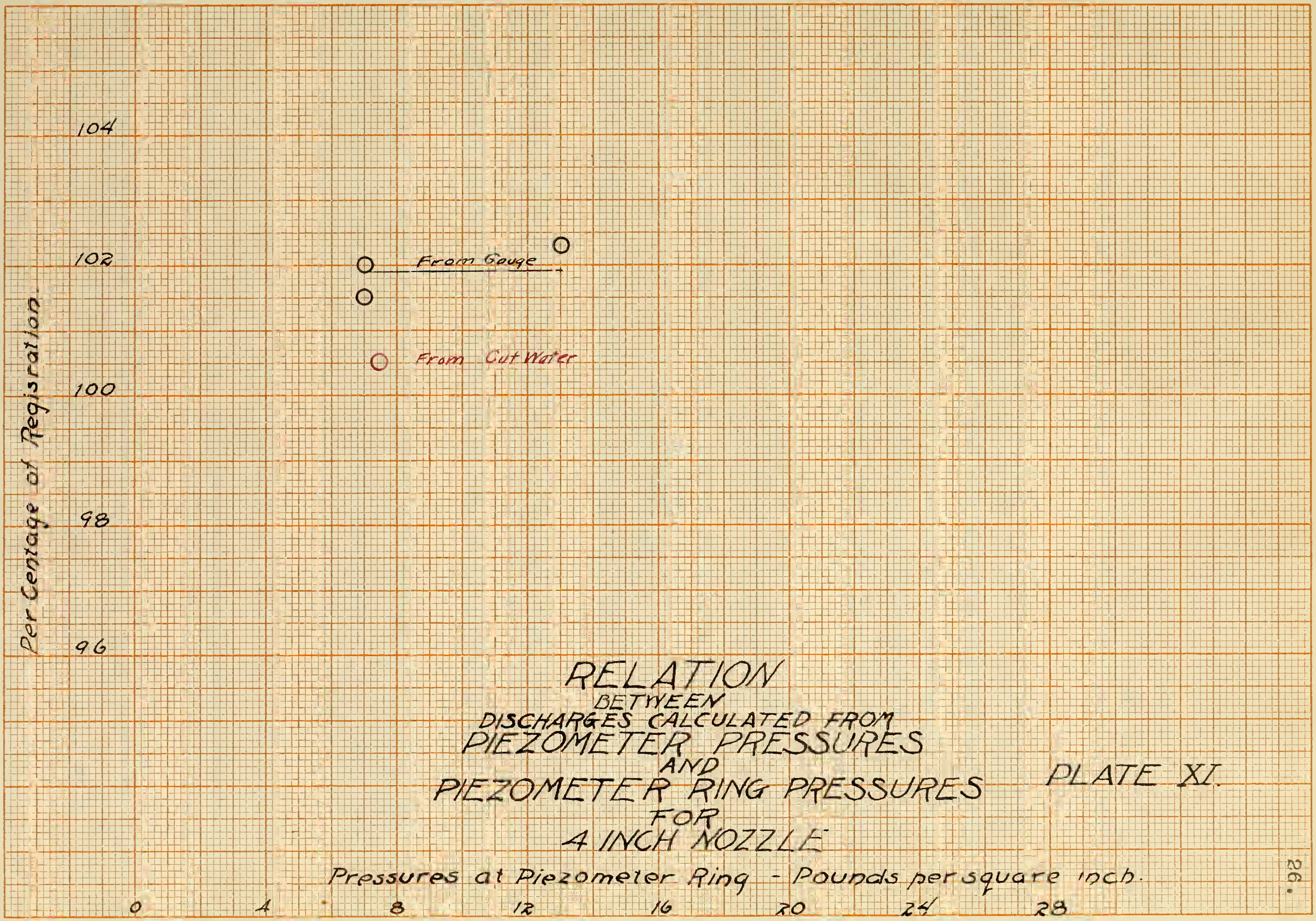
U. OF I. S. S. FORM 3



RELATION
BETWEEN
DISCHARGES CALCULATED FROM
PIEZOMETER PRESSURES
AND
PIEZOMETER RING PRESSURES
FOR
2 INCH NOZZLE

PLATE X.

U. OF I. S. S. FORM 3



RELATION
BETWEEN
DISCHARGES CALCULATED FROM
PIEZOMETER PRESSURES
AND
PIEZOMETER RING PRESSURES
FOR
4 INCH NOZZLE

PLATE XI.

U. OF I. S. S. FORM 3

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